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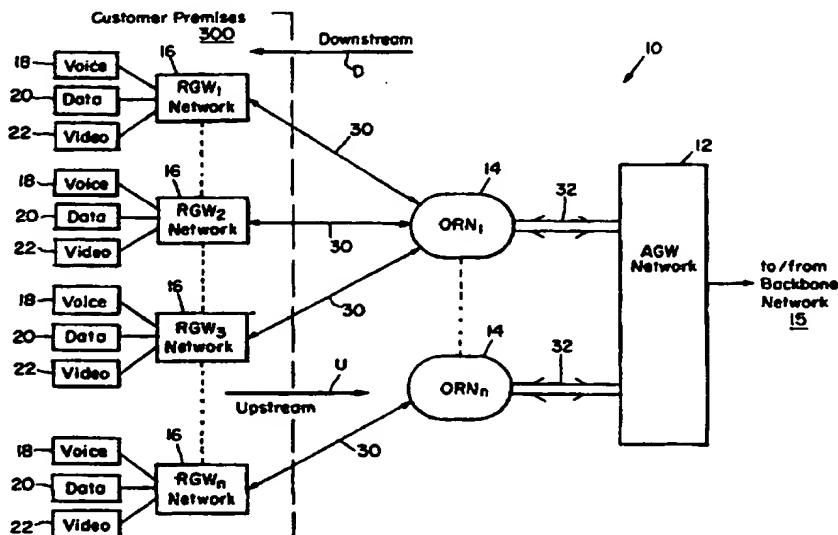
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(57) Abstract

A communication system is described which enables simultaneous communication of voice, data and video bandwidth signals over a communication network. Signals are transported in a downstream direction from a remote node to a regional gateway system and also transported upstream from the regional gateway system to the remote node. In both cases the signals are transported over the same copper wire media.

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MULTIMEDIA OVER VOICE COMMUNICATION SYSTEMBackground of the Invention

Today's public communication network consists of many separate end-to-end service networks. Private
5 leased line networks are deployed for enterprise networking. The Public Switched Telephone Network is utilized for telephony. Data networking utilizes X.25 public packet networks or emerging frame relay or Switched Multimegabit Data Service (SMDS) networks.
10 Television is provided by a separate satellite/fiber/coaxial cable network.

Currently service subscribers, or end users, have separate connections to their homes for each service to which they subscribe. A phone line connects the handset
15 to the local telephone company. Broadband coax cable is used to connect the VCR and TV to the local cable company's transmitter. Also, a separate phone line may be required to connect to the family PC Internet access, computer subscription services, or a local electronic
20 bulletin board.

Separate lines for separate services were expected in the past because the information carrying capacity limited the connection to one service. Today, end users need a full service network that can accommodate nearly
25 all services. Clearly, an efficient solution is needed to take advantage of the old narrowband and new wideband network options, including copper wire, coax and fiber.

Significant investments have been made and are continuing to be made in separate backbone networks for
30 use with specific applications. In addition, new backbone networks are envisioned for new applications. For example, the Internet handles many of today's information and messaging services; interactive video is

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expected to use Asynchronous Transfer Mode (ATM) backbones.

These applications will continue to use these backbone networks. However, the key to delivering these services to the home via one connection is a Multimedia Access Network consisting of a layer of distributed access gateways. These gateways would be compatible with a variety of distribution loop technologies (e.g., copper pairs, fiber/coax, or switched digital fiber) and would permit network operators to upgrade their cable infrastructure and topologies over time without needing to replace the gateways themselves. The access network would use a loop format which will become the basis for the standard multimedia transmission to the home.

While providing service adaption and access, the network would also offer routing to the appropriate backbone, switching and broadcasting, and level 1 gateway (i.e., subscriber interaction) functionality.

Multimedia communication requires the simultaneous delivery of time synchronized audio, video and data signals. A Multimedia Access Network has the task of delivering such signals to and from a switching entity and a multiple subscriber premises which it services. The switching entity acts as a gateway to the rest of the world and allows the subscribers access into the (multiple) backbone networks terminating on it. For this reason the switching entity can be called an Access Gateway (AGW). In general, the switching entity may not be geographically centralized. It may consist of a centralized access node connected with one or more remote nodes.

At the customer's premise, a Residential Gateway (RGW) terminates the multimedia signals from the switching entity AGW and regenerates the communication services being consumed.

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The AGW must communicate with the RGW over some physical media. This media may be wireless or wireline. Multimedia wireless communication is a topic undergoing much research and is an emerging technology. The most
5 common wireline media currently deployed uses Hybrid Fiber Co-Ax (HFC) drops for broadcast video services and twisted pair copper drops for Plain Old Telephone Signals (POTS) services.

U.S. Patent Application Serial No. 08/269,370, now
10 U.S. Patent No. 5,555,244, issued September 10, 1996, entitled "Scalable Multimedia Networks" (incorporated herein in its entirety by reference), is concerned with many of the problems associated with the suitability of multimedia communication services on an AGW.

15 HFC drop networks are deployed by CATV operators and have the advantage that they are based on intrinsically broadband physical media. Co-Axial cable is capable of carrying signals out into the hundreds of megahertz (even a gigahertz on modern cable) to the
20 subscriber. However, HFC networks are deployed as shared media where hundreds (even thousands) of subscribers tap onto one run of cable. Such an architecture is highly cost-effective for broadcast services, but creates a difficult multiple access
25 problem when the RGWs at the subscriber try to communicate with the AGW.

Copper drop networks are deployed by telephone operators and have the advantage that they are star connected. Each RGW has its own connection with the
30 AGW. However, copper, as deployed in the telephone plant, is not an effective broadband physical medium and is fundamentally designed to provide physical transport in the 0-4 KHz base band region over 1300 ohms of wire.

Current (second generation) Fiber-To-The-Curb
35 (FTTC) networks are being deployed by the telephone operator to overcome the above mentioned problem with

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the copper drops. In such FTTC networks, optical fiber connects an Optical Network Unit (ONU) mounted in outside plant (on poles or in manholes) to the AGW. From th ONU, co-ax and (pre-existing) copper runs are
5 used to provide POTS and broadband services to the subscriber.

The problem with such an FTTC network is that it involves "curb cracking." The subscriber's premises' curbside has to be dug for the co-ax to be installed.
10 This is a labor intensive and expensive operation.

A need exists therefore to provide on short runs, such as <1300 ohms of copper, transport for both POTS and broadband data and video signals. If a sufficient reach could be implemented on existing copper, the
15 "curb-cracking" problem would be resolved, and the telephone operators would be able to provide a complete Multiple Access Network system to subscribers.

Summary of the Invention

In accordance with the invention a multimedia
20 system is provided which has the ability to simultaneously transmit voice (POTS), and data and video bandwidth signals from a remote node (RN) to a local node, such as a regional gateway (RGW) system (Downstream Direction) and to send such signals from the
25 RGW to the RN (Upstream) direction. The RN may, for example, comprise an Optical Remote Node (ORN) mounted in an outside plant (on poles or in manholes) which is connected upstream to an Access Gateway Network (AGW) via a wideband fiber optic communication link. The ORN
30 is described in more detail in copending U.S. Application Serial No. 08/651,825, filed concurrently herewith (Attorney Docket No. INC96-02), which is incorporated herein in its entirety by reference. The AGW, in turn, may be connected to the world via a
35 backbone network as described, for example, in the

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aforementioned "Scalable Multimedia Network." On the downstream side, the ORN is connected to a multiplicity of Regional Gateway Networks (RGWs) via existing or added cooper wire. The RGWs may be located, for example, in the basements of apartment buildings. The RGWs simultaneously supply POTS and multimedia signals to and from subscribers in the apartments after separating out the various signals from the channels in which they are transported.

10 In accordance with the invention, three transport channels are utilized to transport signals over the copper wire media extending between the ORN and RGWs: a POTS, or voice channel, for bi-directional transport of POTS bandwidth signals, an upstream channel for
15 bi-directional transport of upstream bandwidth signals between the RGWs and the ORN, and a downstream channel for bidirectional transport of downstream bandwidth signals between the ORN and the RGWs.

The voice or POTS channel is coupled to the wire
20 media by a coupling circuit comprised of series connected, low pass and longitudinal filters at the RN and a low pass filter at the RGW. The longitudinal filter is preferably a balanced inductor (BALUN).

The upstream bandwidth signals are modulated at the
25 RGW coupled to the wire media and decoupled at the ORN and demodulated. Preferably Quadrature Phase Shift Keying (QPSK) modulation of a suitable carrier frequency signal at the transmitter and demodulation at the receiver is employed. The downstream bandwidth signals
30 from the ORN are likewise coupled to the media and modulated preferably using a quadrature amplitude modulation (QAM) to transport the broadband downstream signals from the ORN to the RGW where they are decoupled from the media and demodulated.

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Brief Description of the Drawings

Fig. 1 is a block-diagram drawing of a multimedia communication system of the invention.

Fig. 2 is an illustration of a copper drop network cell.

Fig. 3 is an illustration of how the collection area of a network cell may be extended.

Fig. 4 is a plot of the spectrum allocation for the multimedia system of the invention.

Fig. 5 is a schematic diagram of a coupling circuit used at the ORN portion of the system.

Fig. 6 is a schematic diagram of a coupling circuit used at the RGW portion of the system.

Fig. 7 is a block diagram of the preferred modulator for the upstream channel of the invention.

Fig. 8 is a block diagram of the preferred demodulator for the upstream channel of the invention.

Fig. 9 is a block diagram of the preferred modulator for the downstream channel of the invention.

Fig. 10 is a block diagram of a preferred demodulator for the downstream channel of the invention.

Description of the Preferred Embodiment of the Invention

Referring now to Fig. 1, there is shown an advanced "filter to the curb" (FTTC) multimedia network 10 in accordance with the invention which does not require "curb cracking" since the optical remote nodes 14 (ORN_1 --- ORN_n) are connected to the RGWs 16 (RGW_1 , RGW_2 , RGW_3 --- RGW_n) at the customer premises 300 via existing or added copper wire pairs 30. At the upstream side of the ORNs 14 fiber based broadband media 32, such as a Synchronous Optical Network (SONET) based Asynchronous Transfer Mode (ATM) system may be used to provide POTS and Multimedia service to the ORNs from an Access Gateway Network (AGW) 12. The AGW, in turn, provides multimedia access to/from a Backbone Network 15 as

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described in the aforesaid "Scalable Multimedia Network" application.

The RGWs 16 separate out the voice, data and video signals on the respective channels of communication and feed the separated signals to the appropriate voice 18, data 20 or video instruments 22 or sets at the customer/subscriber premises 300.

In order for the copper based FTTC network 10 of the invention to be properly implemented, an analysis of the services to be provided and the physical topology required to deliver the services is required. Table I below summarizes the individual services envisioned for the system and the bandwidth requirements for each. As can be seen, many of the services are highly asymmetrical in their bandwidth requirements, requiring much greater downstream bandwidth than upstream bandwidth.

Table I. Services and Associated Bandwidth Requirements

| Service | Downstream BW Per Session | Upstream BW Per Session |
|------------------------|------------------------------------|--------------------------------------|
| Broadcast Video | 6 Mbps | |
| Video On Demand | 3 Mbps | 1 Kbps* |
| Telephony | 64 Kbps | 64 Kbps |
| Video Teleconferencing | 384 Kbps | 384 Kbps |
| Data Communications | PEAK > 1 Mbps Average = 10 Kbps | Peak > 0.1 Mbps Average = 10 Kbps |

*Assumption on Interactivity

Table II below shows the bandwidth requirement the copper drop will be expected to support for the service mix desired. From this table it is clear that a downstream channel operating at 20+ Mbps and an upstream channel operating at 600+ Kbps would be adequate to support this service mix. These channels must operate over lifeline POTS service to provide the full gamut of desired residential services.

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Table II. Bandwidth Requirements on the Copper Drop for
a Full Compliment of Residential Services

| Service | # of Simultaneous Sessions | Downstream Bandwidth | Upstream Bandwidth |
|-----------------|----------------------------------|--|--|
| CATV | 0-2 | 0-12 Mbps | |
| VOD | 0-1 | 0-3 Mbps | 1 Kbps |
| Telephony | 0-1 | 0-64 Kbps | 64 Kbps |
| Video Teleconf. | 0-1 | 0-384 Kbps | 384 Kbps |
| Data Comm. | 0-1 | 0- (Peak > 1 Mbps Average = 1 Kbps) | 0- (Peak > 0.1 Mbps Average = 1 Kbps) |
| TOTAL | 0-6 | 0-16.448 Mbps | 0-549 Kbps |

Another important requirement is the reach or signal transmission distance over copper wire. Fig. 2 shows a drop network cell at the center of which the ORN 14 is located. It is envisioned that approximately 500 subscriber premises each allocated 0.5 acres (after accounting for overhead) can be reached from a single ORN.

To cover 250 acres of area, the drop network cell needs to have a diagonal "radius" of 2,000 feet. For suburban/rural areas, collection over a greater area can be effected using the double-star topology shown in Fig. 3 where one or more satellite ORNs 14' can be homed onto the main ORN 14M using pole-to-pole or manhole-to-manhole co-ax cable over which power and broadband connectivity can be extended.

Based upon the analysis in Tables I and II, it may be seen that a Multimedia-Over-Voice (MOV) copper loop needs to have the ability to transport:

- I. Life-line POTS signals;
 - II. 20+ Mbps downstream signals; and
 - III. 600+ Kbps upstream signals
- simultaneously between the ORN 14 and the RGW 16.

Fig. 4 shows a Frequency Division Multiplex (FDM) architecture for such a loop. The POTS channel occupies the 0-4 KHz band, the upstream channel occupies the \geq

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50 KHz to \leq 1.8 MHz band labeled return link (f1 to f2) and the downstream channel occupies the 2 MHz to 8 MHz band labeled QAM link which stands for Quadrature Amplitude Modulated (f3 to f4).

5 Coupling System and POTS Channel 50A/50B

Turning now to Figs. 5 and 6, the coupling system for combining and separating (orthogonalizing) the POTS bandwidth channel and the upstream and downstream bandwidth channels as appropriate at the ORN (Fig. 5) and at the RGWs (Fig. 6) will now be described.

First the connectivity of the channel signals coupling circuits will be described in general, then the details of the various circuit components will be described. At the ORN 14 the POTS channel signals from the AGW 12 on the ONU 32, are coupled across the input Tip and Ring wires (T&R) of the ORN coupling circuit 50A. The QAM modulated downstream channel signals at 20+ Mbps from the downstream modulator 90 are coupled to amplifier driver 46 of ORN low impedance coupling circuit 44 for coupling to the output Tip and Ring (To/Ro) wires for transmission over media 30 to the RGW 16. The upstream channel signals at 600 Kbps are input on Tip and Ring wires To/Ro and are coupled through transformer T₁, to output or driver amplifier 48 to the upstream demodulator 60B.

Conversely, the RGW 16 coupling circuit 50B (Fig. 6) the POTS channel signals from the ORN 14 are input to the Tip and Ring input wires and passed directly through Filter LPF1' to the output Tip and Ring leads (To/Ro) to the telephone unit 18 at the subscriber premises. The downstream channel signals from the downstream transmitter modulator 90 at 20+ Mbps are also coupled across input T&R leads and passed to the input coil 42' of transformer T1' to amplifier 48' where they

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are coupled to downstream demodulator - Fig. 10, at the RGW 16.

The upstream channel signals from the subscribers consist mainly of data and/or Video On Demand or teleconferencing signals. These signals are coupled to the input terminal 61 of a Dual Rail Splitter circuit 64 of Upstream Modulator 60A (Fig. 7). The modulated output upstream channel signals are coupled to input amplifier 46' of low impedance circuit 44' of the coupling circuit 50B at the RGW 16 (Fig. 6); where they are coupled via transformer T1' onto the output Tip and Ring Leads T_o and R_o onto the copper wire media 30 to the ORN 14 for demodulation at the upstream demodulator 60B (Fig. 8).

The POTS channel signals must not interfere with nor be interfered by the other channels. The band 0-4 KHz must be transparently provided to the POTS system. In its own turn, the POTS system, unless properly conditioned, consists of a large amount of interference outside the 0-4 KHz band which would corrupt the other channels. For example, Dial pulses in the POTS system cause 48V transitions that are abrupt and have an abundance of high frequency content. The sudden engagement of a ringing signal on the POTS channel and its subsequent dis-engagement can cause up to 200V transients that can be very disruptive to the other channels. Furthermore, the ringing signal is applied by grounding the Tip line T while applying the ringing signal to the Ring Line R. This unbalanced signal has high common mode voltages present. Such "longitudinal" signals can be converted to interfering "metallic" (differential) signals by the longitudinal unbalance (poor common mode rejection ratios) of the receiving front ends of the other channel(s).

Passive filtering in the form of a Low Pass Filter LPF1 is used at coupling circuit 50A (Fig. 5) at the ORN

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14 for a Low Pass Filter (LPF) function to preserve the
life-line nature of this service. A longitudinal filter
LF1 is used only at the ORN coupling circuit 50A. LF1
produces a high impedance in the longitudinal path while
5 being essentially transparent in the metallic path. The
longitudinal filter LF1 is a balanced inductor (BALUN)
in the form of series connected 2 mH inductors L5 and L6
on the Tip (T) and Ring (R) lines respectively. The
BALUN is normally bifilar wound as indicated by the
10 polarity dots. The millihenray (mH) inductors L1-L4 at
the ORN L1'-L4' at the RGW are provided to present a
high impedance in the data band channels and to prevent
the POTS low pass filter LPF1 from attenuating the high
frequency signals. Note that the longitudinal filter
15 LF1 (described above) is not required at the RGW end 16
(Fig. 6) because the telephone is a balanced
("floating") instrument and produces no longitudinal
signals.

Low pass filters LPF1 at the ORN end coupling
20 circuit 50A and LPF1' at the RGW end coupling circuit
50B, respectively, are based on a fourth order 0.25 db
ripple Tchebyschef response, scaled to an impedance of
900 Ω and a cut-off frequency of 50 KHz. Filtering at
600 Ω can be achieved by impedance scaling the
25 filtering. A "click" filter CF1 is included across the
Tip and Ring lines and is only visible to ringing
signals. Low impedance coupling circuits 44 and 44'
have low impedance (compared to 900 Ω) and do not
seriously degrade the response.

30 In the upstream and downstream frequency band
channels the copper wire 30 has a characteristic
impedance in the 100 Ω neighborhood unlike the
600 Ω /900 Ω impedance level for the voice channel. The
low impedance coupling circuits 44 and 44' can therefore
35 comprise 1:1 pulse transformers T1 and T1' with a
capability to pass the 50 KHz through 10 MHz combined

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bandwidth of the upstream and downstream data and video bandwidth signals at a $100\ \Omega$ source/ $100\ \Omega$ load impedance level. This can be readily achieved using $<0.25\ \text{mH}$ coils 40, 40' on a high frequency ferrite or a powdered iron toroidal core 42, 42' (carbonyl C or better). The windings present minimal impedance relative to the impedance of the $0.018\ \mu\text{F}$ capacitor C1, C1' in series with T1, T1' at $\leq 4\ \text{KHz}$. Therefore, the coupling circuits 44 and 44' look like they are not present to the POTS band. The $0.018\ \mu\text{F}$ coupling capacitor C1 has a low impedance across the upstream and downstream bands and therefore does not excessively attenuate coupling.

The 20 Hz POTS ringing signals and 48V DC POTS transients that may pass through the POTS Low Pass Filters LPF1 produce most of the voltage over the $0.018\ \mu\text{F}$ coupling capacitor C1 and do not create large voltages across T1. This prevents saturation from occurring at the coupling amplifiers 46, 48.

The "click" filters CF1, CF2, respectively in series with respective $0.47\ \mu\text{F}$ capacitors C5, C5' across the tip (T) and ring (R) terminals suppresses ringing transients.

The Upstream Channel

Figs. 7 and 8 illustrate a preferred embodiment of the respective digital modulators and demodulators of the upstream channel system of the invention.

The upstream modulator at the RGW maps the digital sequence signals from the subscriber onto a carrier frequency signal having a waveform appropriate for transmission over the copper pair media. In turn, the demodulator at the ORN processes the media corrupted received waveforms to reproduce or recover the original digital sequence. A simplified version of the well-known modulation and demodulation process follows. For more details reference is had to the text *Digital*

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Communications, 2d Edition, by John G. Proakis (McGraw-Hill) © 1989, 1983, which is incorporated herein in its entirety by reference.

The spectrum of the 600 Kbps upstream channel, which may contain up to 1 Kbps VOD signals, 64 Kbps telephony signals and 394 Kbps video teleconferencing signals, is sandwiched between the low frequency narrow band spectrum of the POTS channel and the high frequency wide bandwidth downstream channel. The available bandwidth ranges from about 50 KHz to about 1.8 MHz which is a band of about 1.75 MHz. If only video services are required, then the only purpose of the upstream channel is to provide service control from the subscriber to the network via the ORN's 14. Even a 64 Kbps frequency would be adequate for this response with enough left over to provide low bandwidth data communication services over the copper wire medium 30. For such an upstream transmission, a well-known angle based modulation system, such as Frequency Shift Keying (FSK) modulation, suffices and is very cost effective in spite of its low spectral efficiency. To achieve a high bit rate, a well-known Quadrature Phase-Shift Keying (QPSK) based system is preferred. To provide a bit rate of 2.048 Mbps (which is >600 Kbps), a baud rate of 1.024 MHz is used. With a 50% excess bandwidth raised cosine pulse spectrum (see Proakis, *supra*, p. 536) as the basic pulse shape being modulated on each of the I and Q axis, the passband signal extends from 256 KHz to 1.792 MHz, which fits nicely into the desired spectral window and intersymbol interference is avoided.

A modulator circuit 60A (Fig. 7) is provided at the RGW 16 which accepts the input data in standard alternate mark inversion (AMI) bipolar format from the subscriber at 2.048 Mbps. The input signal is split into two 1,024 Mbps bit streams labeled ST1 and ST2, using well-known Dual Rail Splitter circuit 64.

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Sampling system clock 72 is used by circuit 64 to sample the input stream at one-half the input data rate to produce the two separate streams ST1 and ST2 of respective positive and negative going pulses. The baseband bit streams are then Pulse Amplitude Modulated onto a carrier frequency signal using raised cosine 50% Excess Bandwidth sinusoidal PAM encoders 62 and 62', respectively, for each data stream. Circuit 67 divides the 2.048 Mbps clock by two and multipliers 66 and 66' create the 90° phase shifted outputs ST3, ST4 (quadrature rails). After raised cosine 50% Excess Bandwidth pulse amplitude modulation of the two bit streams, the two modulated bit streams are re-combined in summing amplifier 68, and passed through (0.256 MHz to 1.792 MH) Low Pass Filter 70. Filter 70 rejects all harmonic content present in the modulating clocks. The output of filter 70 is coupled to amplifier 46' of coupling circuit 50B of Fig. 6 for transmittal over the copper pair 30 to the ORN14 upstream.

At the ORN14 (referring to Fig. 8), the modulated upstream channel signals from coupling circuit 50A at the ORN14 are received at receive filter 74 of demodulator 60B. Filter 74 rejects all signals other than the 2.048 Mbps signals occupying the 50 KHz to 1.8 MHz upstream channel.

Carrier recovery circuit 76 recovers the carrier signal used in the QAM modulation circuit of Fig. 7 to produce sine and cosine quadrature clock/pulses. Multiplier circuits 78 and 78' recover the transmitted modulated rails which are passed through Low Pass Filters 81 and 81' to Equalizer 80.

The split rail demodulated bit stream is equalized to compensate for transmission losses in equalizer 80 and detected by decision device 82, which includes a slicer circuit (not shown) and a comparator (not shown) which determines when the incoming signal exceeds a

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predetermined threshold and is therefore a valid data signal. The two demodulated bit streams ST1 and ST2 are combined in (well known) Dual Rail combiner 84 by alternating bits from the two rails to re-create the
5 2.048 Mbps upstream data from the RGW modulator 60A. The demodulated signals are coupled to AGW12 via ONU media 32. Carrier recovery circuit 76 is also used to regenerate the 2,048 Mbps clock signal from the RGW16 to synchronize the equalizer and decision device circuits
10 80 and 82, respectively.

The Downstream Channel

The Downstream Channel modulator 90 and demodulator 900 are depicted in general in Fig. 9 and Fig. 10, respectively. In accordance with Table II a full
15 complement downstream channel requires up to 16.448 Mbps. The downstream channel uses a frequency band starting from 2.0 MHz. Either 16 Quadrature Amplitude Modulation (QAM) or 64 QAM technology (as defined in Proakis, supra, pp. 227-285) may be used to transport
20 the downstream channel over the copper wire from the ORN 14 to the RGW 16. A 16 QAM technology can be used to achieve a 20 Mbps bit rate in which case, the baud rate must be 5 Mbaud. Also, 20% excess bandwidth raised cosine pulses are preferably the basic pulse shapes used
25 on each of the I, Q axis, in which case the passband signal will occupy the 2 MHz to 8 MHz band. If the same band is used with 64 QAM, a bit rate of 30 Mbps can be achieved.

Normally, the downstream channel will suffer from
30 reflections due to bridge taps (unterminated wire attached to the copper loop) in the form of incorrectly made splices. Thus, even though linear equalization will resolve dispersion due to straight wire, a Decision Feedback Equalizer (DFE) circuit 120 is used in the
35 Modulator 90 to eliminate echoes due to reflections. A

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16 Tap Feed Forward Equalizer 102 (8 feedforward taps and 8 feedback taps) in the DFE 120 provides adequate performance for up to 2,000 feet of 24 gauge copper wire media.

5 Since energy can be collected from impulse noise sources (chattering relays, light dimmers, electric motors, etc.), therefore interleaving along with Forward Error Correction (FEC) is employed to eliminate degraded performance due to impulse noise. FEC also enhances the error performance due to far end cross talk between MOV
10 signals in the wires running adjacently in the binder group.

When High Bit Rate Downstream Bandwidth Signals from the AGW12 and received at the ORN14 for transmittal
15 to an RGW they are first coupled to input port 96 of downstream channel 90 and split into I and Q channels by raised cosine quadrature amplitude modulation carrier by oscillator 95 at respective cosine modulator 94, and sine modulator 94'. The digitally modulated I and Q
20 downstream signals are coupled to DFE circuit 120 comprising feed forward equalizer 102 coupled to respective I and Q rail summing amplifiers 104, 104' and threshold detectors 106, 106'; the outputs of which are combined in combiner 110 and passed to low impedance
25 amplifier 46 at the ORN coupling circuit 50A for transmission over the copper wire media 30 to the RGW. Acquisition and Tracking Loops circuit 92 provides clock synchronization pulses.

The downstream demodulator 900 is functionally
30 equivalent to the upstream demodulator 60B. The QAM modulated downstream carrier signal from the RGW coupling circuit 50B at the low impedance amplifier 48' is coupled to receive filter 740 and demodulated into two bit streams by mixing with the carrier signal in
35 mixers 780 and 780'. The carrier signal is recovered in circuit 760. The demodulated signals are passed through

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low-pass-filters 781, 781', equalized in equalizer 800 and detected in decision device 820. The detected signals are combined in combiner 840 and coupled to the subscriber at the customer premises 300.

5 A multimedia over voice communication system has been described above using 16 QAM a 20 Mbps (18 Mbps after FEC) signal along with a 2.048 Mbps upstream signal which can be transferred over 2,000 feet of 24 gauge wire in the presence of impulse noise and 1% FEXT
10 while maintaining a Bit Error Rate (BER) of $<10^{-8}$. This capability exists over POTS. The POTS channel simultaneously meets all requirements imposed on it for local telephony.

15 Having thus described a particular embodiment of the invention, various alterations, modifications and improvements will readily occur to those skilled in the art. Such alterations, modifications and improvements as are made obvious by this disclosure are intended to be part of this description though not expressly stated
20 herein, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only, and not limiting. The invention is limited only as defined in the following claims and equivalents thereto.

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CLAIMS

We claim:

1. A communication system for simultaneous
communication of voice, data and video bandwidth
signals in a downstream direction from a remote
node to a local node and upstream from the local
node to the remote node over copper wire media
comprising:
 - a) a first coupling circuit at the remote node
for coupling respective voice, data and video
bandwidth signals to a respective first voice,
downstream and upstream channel of the media;
 - b) a second coupling circuit at the local node
for coupling respective voice, data and video
bandwidth signals to said second respective
voice channel and said downstream and upstream
channels of the media.
2. The system of Claim 1 wherein the voice channel has
a bandwidth extending up to 4 KHz, the upstream
channel bandwidth extends from above 4 KHz to less
than 2.0 MHz and the downstream channel from 2 MHz
to at least 8 MHz.
3. The system of Claim 1 wherein the first coupling
circuit is operatively associated with the remote
node and comprises a first passive low pass filter
in series with a passive longitudinal filter and
the second coupling circuit is operatively
associated with the local node and comprises a
second passive low pass filter.
4. The system of Claim 3 wherein the longitudinal
filter is comprised of a balanced inductor for
providing a high impedance along a longitudinal

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channel path while being essentially transparent along a metallic channel path.

5. The system of Claim 1 wherein the upstream channel is comprised of a modulator which splits the data bandwidth signals from the local node into two bit streams each of which is separately pulse amplitude modulated onto a carrier frequency signal by a raised cosine function on each of two orthogonal axes and combined and passed through a low pass filter in an upstream direction toward the remote node and a demodulator which receives the modulated and combined signals from the remote node and passes them through a receive filter having a pass band to a carrier recovery circuit where the carrier frequency signal is recovered and mixed with the modulated and combined signal to provide a demodulated data bandwidth signal in each of two alternate data streams which are then equalized and combined to form a data bandwidth signal for transmission over the media toward the local node.
6. A communication system for simultaneous communication of voice, data and video bandwidth signals in a downstream direction from a remote node to a local node and upstream from the local node to the remote node over copper wire media comprising:
 - a) a first coupling circuit at the remote node for coupling a first voice channel signal and a modulated downstream channel signal to the media and for receiving a second voice channel signal and modulated upstream channel signal from the media;
 - b) a second coupling circuit at the local node for receiving the first voice channel signal

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and modulated downstream channel signal from the media and for coupling an upstream channel signal to the media.

- 5 7. The system of Claim 6 wherein the first and second voice channel signals have a bandwidth extending from 0 to 4 KHz, the upstream channel signal has a bandwidth which extends from 50 KHz to 1.8 MHz and the downstream channel signal has a bandwidth which extends from 2 MHz to at least 8 MHz.
- 10 8. The system of Claim 6 wherein the first coupling circuit is operatively associated with the remote node and comprises a first passive low pass filter in series with a passive longitudinal filter and the second coupling circuit is operatively
15 associated with the local node and comprises a second passive low pass filter.
9. The system of Claim 8 wherein the longitudinal filter is comprised of a balanced inductor for providing a high impedance along a longitudinal
20 path while being essentially transparent along a metallic path.
10. The system of Claim 6 including an upstream modulator which receives the upstream channel signal from a subscriber and splits the signal into
25 two bit streams each of which is separately pulse amplitude modulated onto an upstream carrier frequency signal by a raised cosine function on each of two orthogonal axes and combined and passed to the second coupling circuit for transport in an
30 upstream direction toward the first coupling circuit at the remote node and an upstream demodulator which receives the modulated and

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- combined signals from the first coupling circuit and passes them through a pass band receive filter, a carrier recovery circuit where the upstream carrier frequency signal is recovered and mixed
- 5 with the modulated and combined signal to provide a demodulated upstream channel signal in each of two alternate data streams which are then equalized and combined to reconstruct the upstream channel signal for transmission to a backbone network.
- 10 11. A remote node coupling system for coupling communication signals from a backbone network to and from a local node over a copper wire media, the system comprising tip and ring input terminals coupled to a POTS communication channel, a remote
- 15 node low impedance circuit having a downstream channel input signal coupled over a low impedance path to a tip and ring output terminal of the copper wire media and an upstream output signal coupled to a demodulator for demodulation and
- 20 coupling to said backbone network.
12. The local node coupling system of Claim 7 including a click filter across the tip and ring input terminals.
13. The local node coupling system of Claim 7 wherein
- 25 the local node low impedance circuit is comprised of an input and output amplifier coupled to the secondary windings of a transformer and where the primary windings of the transformer are AC coupled across the tip and ring output terminals.
- 30 14. The local node coupling system of Claim 10 further including a click filter across the tip and ring input leads and a low pass filter in a conductive

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path between the input tip and ring leads and the output tip and ring leads.

15. The system of Claim 6 including a downstream digital modulator which receives the downstream channel signal and pulse amplitude modulates it onto a downstream carrier frequency signal for coupling to the first coupling circuit, and a downstream digital demodulator coupled to the second coupling circuit for receiving the modulated downstream channel signal in which the downstream carrier frequency signal is recovered and mixed with the modulated downstream channel signal to produce a demodulated downstream channel signal for transmission to a subscriber.
16. A local node coupling system for coupling communication signals from a subscriber to and from a copper wire media, the system comprising tip and ring input terminals coupled to a subscriber's telephone, a local node low impedance circuit having an upstream channel input signal and a downstream channel output signal, and wherein the output signal is coupled to a digital demodulator for demodulation and coupling to a subscriber's video and data terminals, and the input signal is coupled over a low impedance path to a tip and ring output terminal of the copper wire media.
17. A downstream channel for bidirectionally transporting downstream bandwidth signals between a local node and a remote node over copper wire media comprising:
- a downstream modulator operatively associated with the remote node for pulse amplitude

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- modulating the downstream bandwidth signals onto a downstream carrier frequency signal;
- 5 b) a remote node coupling circuit for coupling the downstream carrier frequency signal onto the copper wire media for transport to the local node coupling circuit;
- 10 c) A local node coupling circuit for coupling the downstream carrier frequency signal from the copper wire media to a demodulator circuit for recovery of the downstream bandwidth signals; and
- an upstream channel for bidirectionally transporting upstream bandwidth signals between said local node and said remote node over said copper wire media comprising:
- 15 d) an upstream modulator operatively associated with the local node for pulse amplitude modulating the upstream bandwidth signals onto an upstream carrier frequency signal;
- 20 e) said local node coupling circuit also coupling the upstream carrier frequency signal onto the copper wire media for transport to the remote node coupling circuit;
- 25 f) said remote node coupling circuit also coupling the upstream carrier frequency signal from the copper wire media to a demodulator circuit for recovery of the upstream bandwidth signals; and
- a voice channel for bidirectionally transporting voice bandwidth signals between said local node and said remote node over said copper wire media comprising:
- 30 g) input tip and ring terminals connecting a telephone to said local node coupling circuit for coupling voice bandwidth signals from the telephone to said copper wire media and tip
- 35

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and ring output terminals for coupling the voice bandwidth signals from the copper wire media to the remote node.

18. The system of Claim 17 wherein the bandwidth of the downstream signals is greater than 2 MHz; and the bandwidth of the upstream signal is greater than 4 KHz and less than 2 MHz.
19. The system of Claim 17 wherein the downstream and upstream modulators are quadrature amplitude modulators.
20. The system of Claim 17 wherein the downstream signals include broadcast video signals occupying 12 Mbps of bandwidth, video on demand signals occupying 3 Mbps of bandwidth and telephony signals occupying 64 Kbps of bandwidth, and wherein the upstream signals include said video demand signals and telephony signals.
21. A method of communication for simultaneous communication of voice, data and video bandwidth signals in a downstream direction from a remote node to a local node and upstream from the local node to the remote node over copper wire media comprising the steps of:
- a) coupling respective voice, data and video bandwidth signals to a respective first voice channel, downstream channel and upstream channel of the media;
 - b) coupling respective voice, data and video bandwidth signals to a second respective voice channel and downstream channel and upstream channel of the media.

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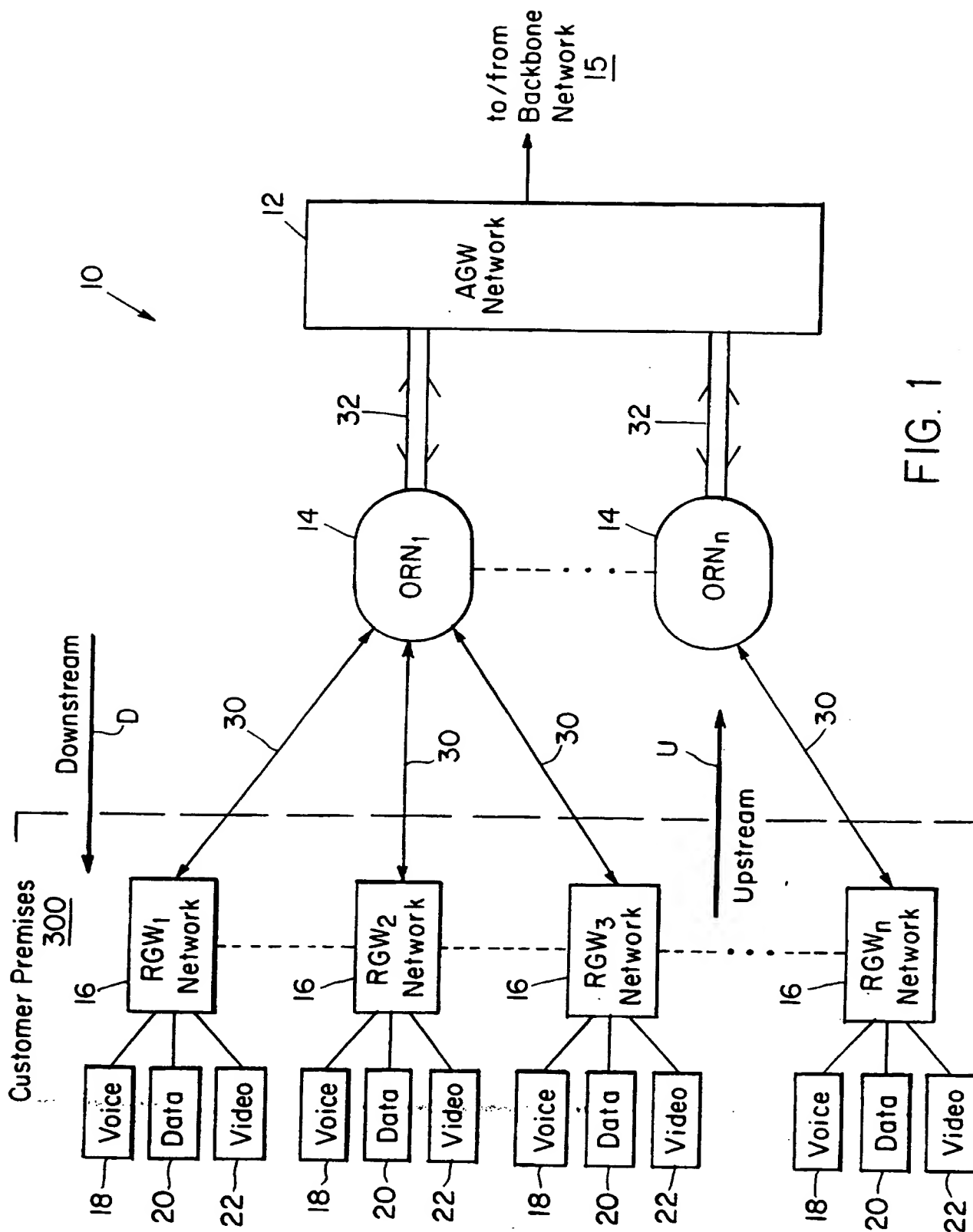
22. The method of Claim 21 wherein the voice channel has a bandwidth extending up to 4 KHz, the upstream channel bandwidth extends from above 4 KHz to less than 2.0 MHz and the downstream channel from 2 MHz to at least 8 MHz.
23. The method of Claim 21 including the steps of splitting the data bandwidth signals into two bit streams each of which is separately pulse amplitude modulated onto a carrier frequency signal by a raised cosine function on each of two orthogonal axes and combined and passed through a low pass filter in an upstream direction toward the remote node and a demodulator which receives the modulated and combined signals from the remote node and passes them through a receive filter having a pass band to a carrier recovery circuit where the carrier frequency signal is recovered and mixed with the modulated and combined signal to provide a demodulated data bandwidth signal in each of two alternate data streams which are then equalized and combined to form a data bandwidth signal for transmission over the media toward the local node.
24. A method for simultaneous communication of voice, data and video bandwidth signals in a downstream direction from a remote node to a local node and upstream from the local node to the remote node over copper wire media comprising the steps of:
- a) coupling a first voice channel signal and a modulated downstream channel signal to the media;
 - b) receiving a second voice channel signal and modulated upstream channel signal from the media;

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- 5 c) receiving the first voice channel signal and
 modulated downstream channel signal from the
 media; and
- d) coupling an upstream channel signal to the
 media.
25. The method of Claim 24 wherein the first and second
voice channel signals have a bandwidth extending
from 0 to 4 KHz, the upstream channel signal has a
bandwidth which extends from 50 KHz to 1.8 MHz and
10 the downstream channel signal has a bandwidth which
 extends from 2 MHz to at least 8 MHz.
26. A method of bidirectionally transporting downstream
bandwidth signals between a local node and a remote
node over copper wire media comprising the steps
15 of:
- a) modulating the downstream bandwidth signals
 onto a downstream carrier frequency signal;
- b) coupling the downstream carrier frequency
 signal onto the copper wire media for
20 transport to a local node coupling circuit;
- c) coupling the downstream carrier frequency
 signal from the copper wire media to a
 demodulator circuit for recovery of the
 downstream bandwidth signals; and
- 25 bidirectionally transporting upstream bandwidth
signals between said local node and said remote
node over said copper wire media comprising the
steps of:
- d) modulating the upstream bandwidth signals onto
 an upstream carrier frequency signal;
- 30 e) coupling the upstream carrier frequency signal
 onto the copper wire media for transport to
 the remote node coupling circuit;

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- f) coupling the upstream carrier frequency signal from the copper wire media to a demodulator circuit for recovery of the upstream bandwidth signals; and
- 5 bidirectionally transporting voice bandwidth signals between said local node and said remote node over said copper wire media comprising the steps of:
- 10 g) coupling voice bandwidth signals from a telephone to said copper wire media and coupling the voice bandwidth signals from the copper wire media to the remote node.



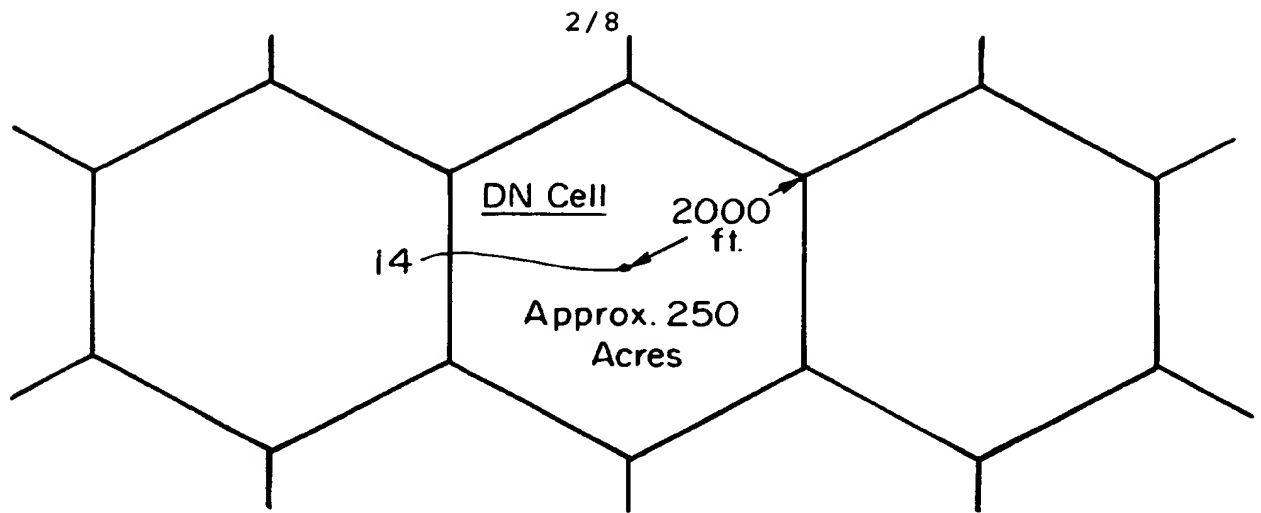


FIG. 2

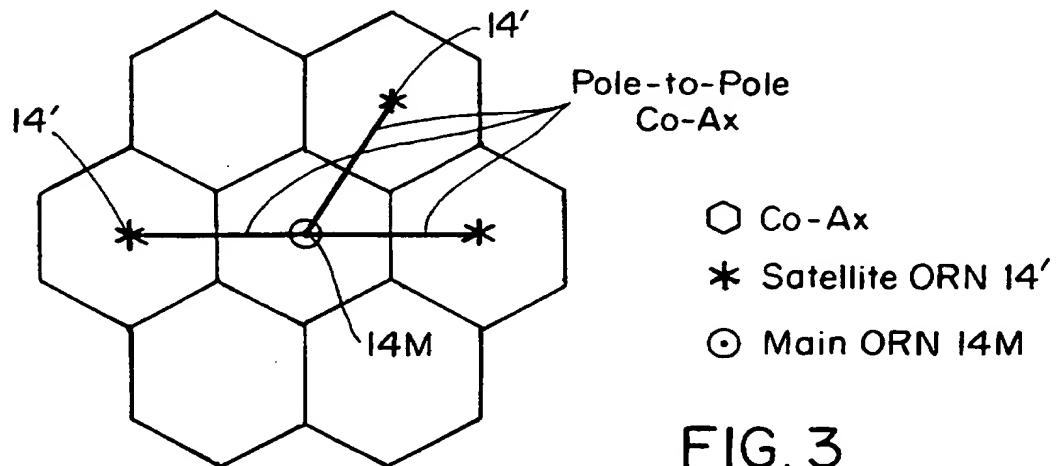


FIG. 3

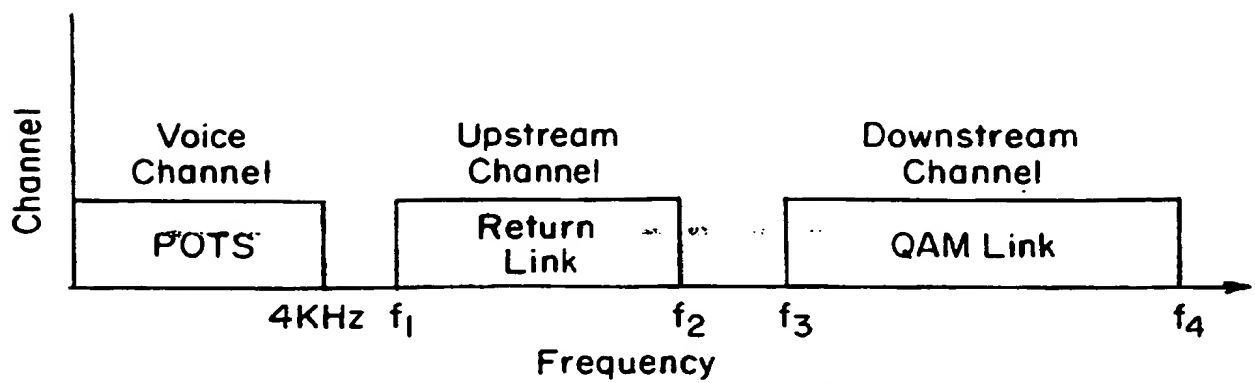


FIG. 4

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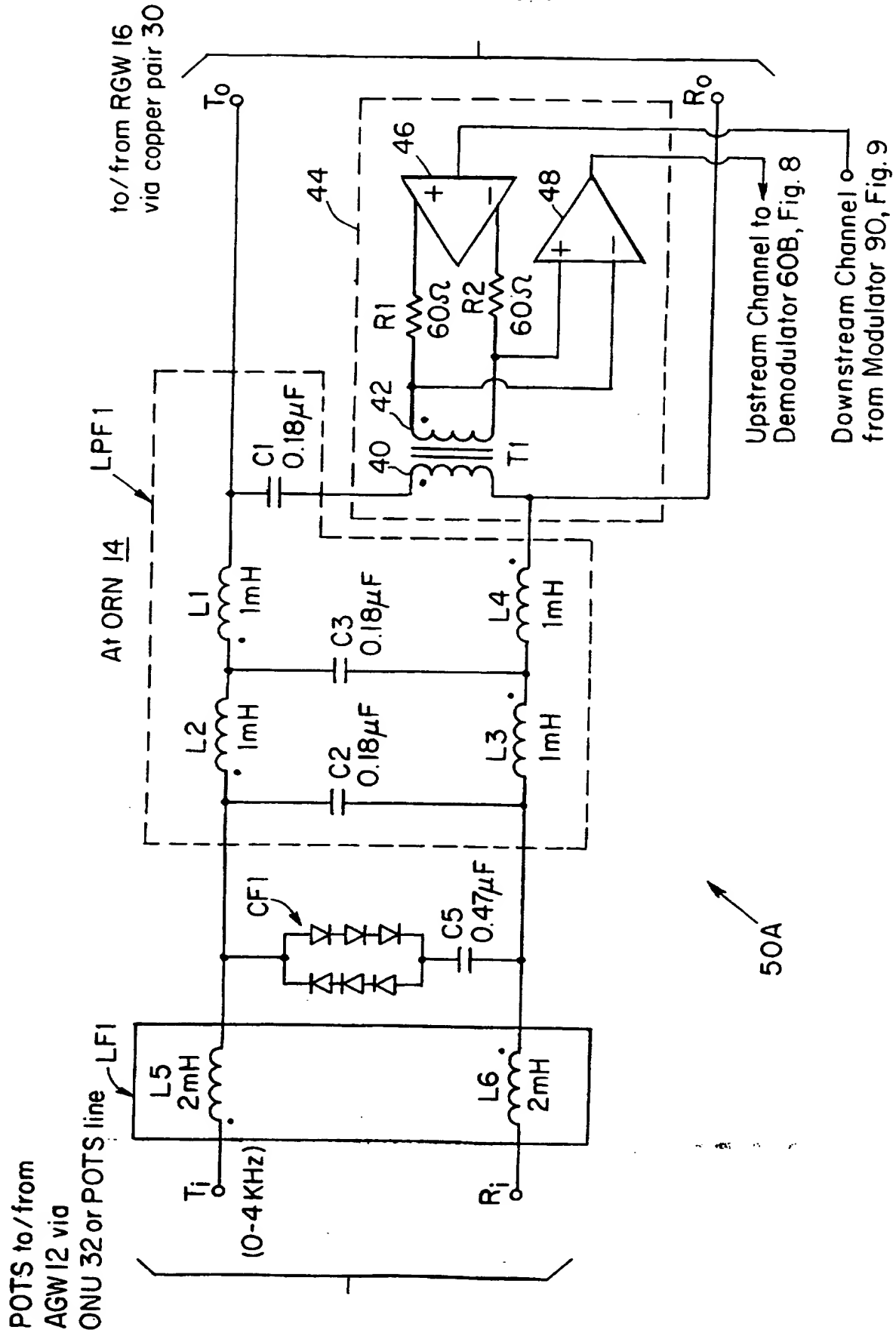


FIG. 5

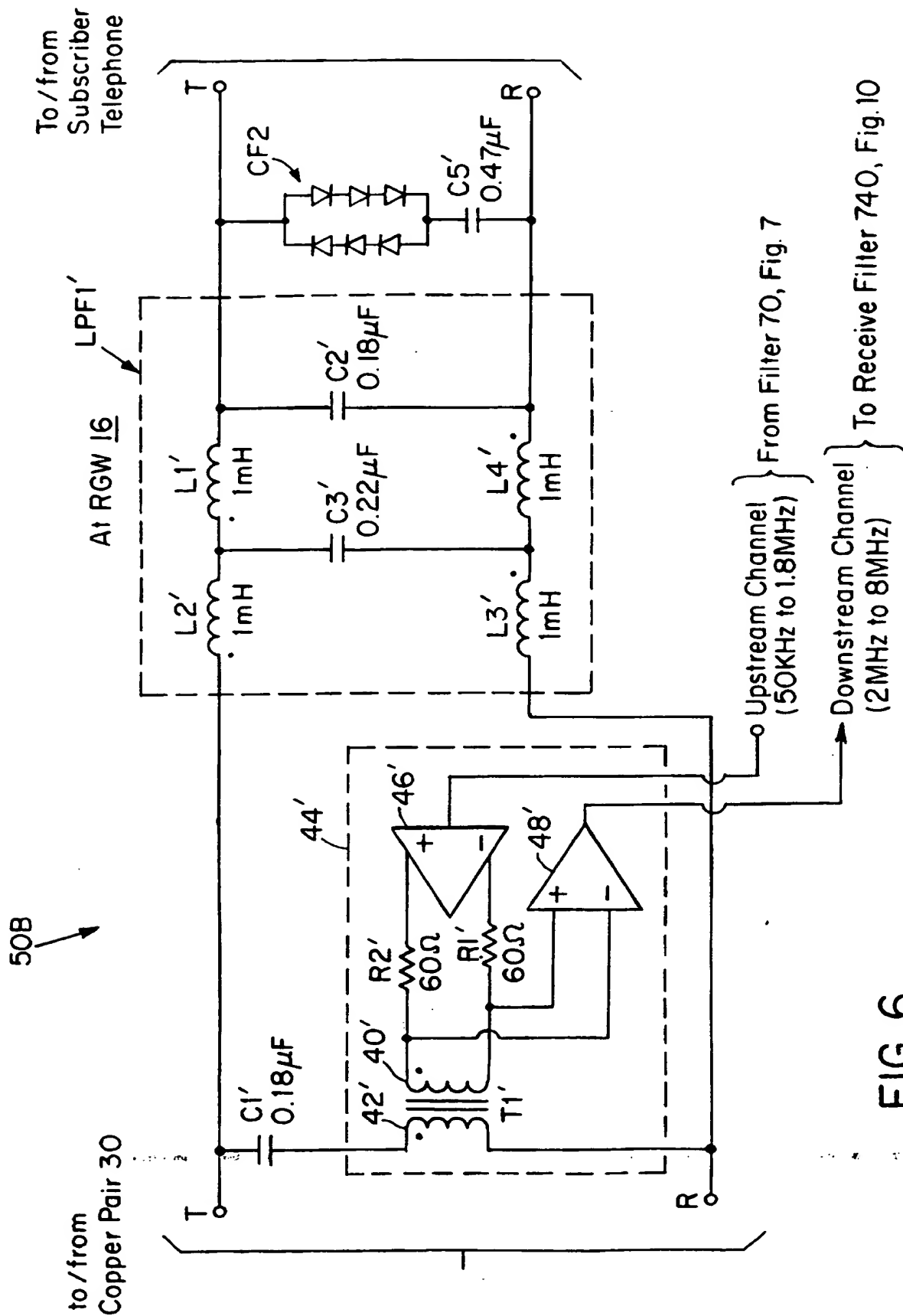


FIG. 6

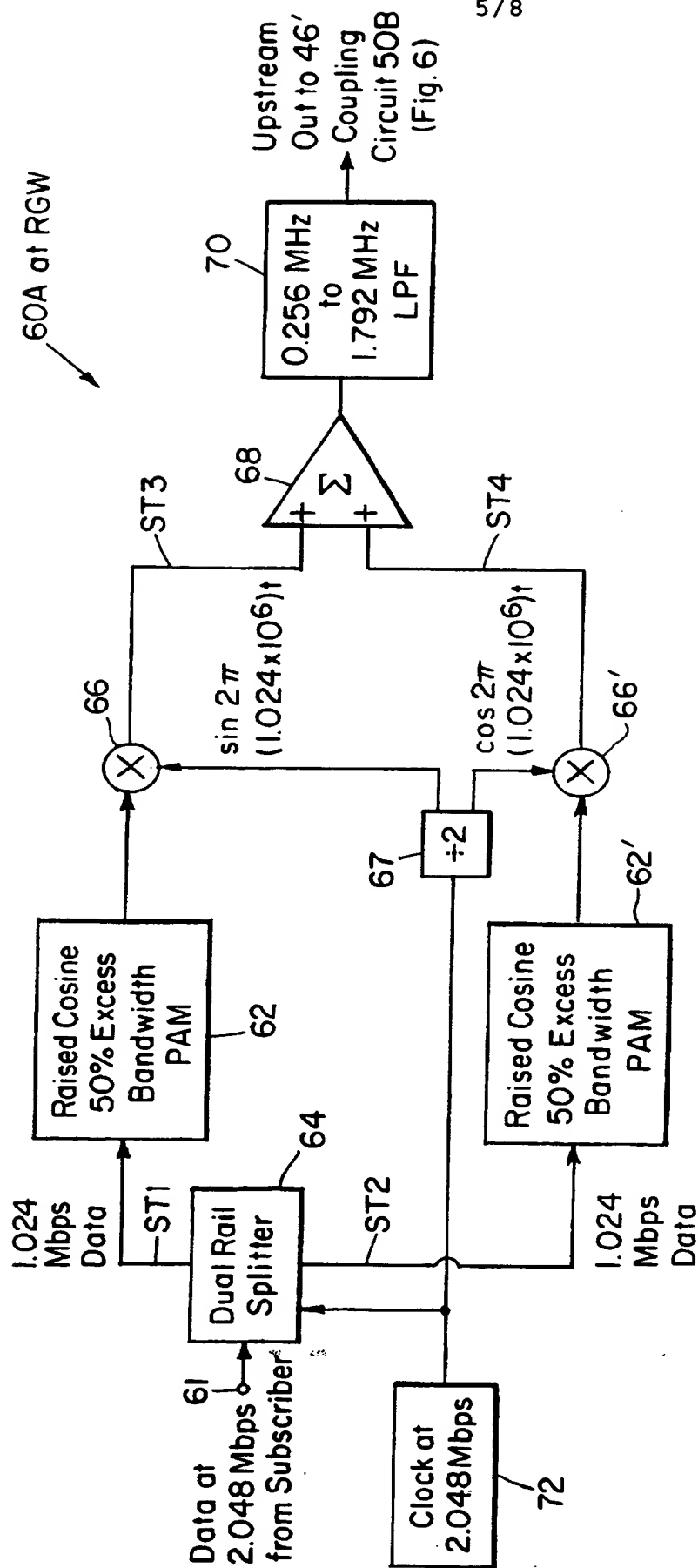


FIG. 7
UPSTREAM MODULATOR at RGW

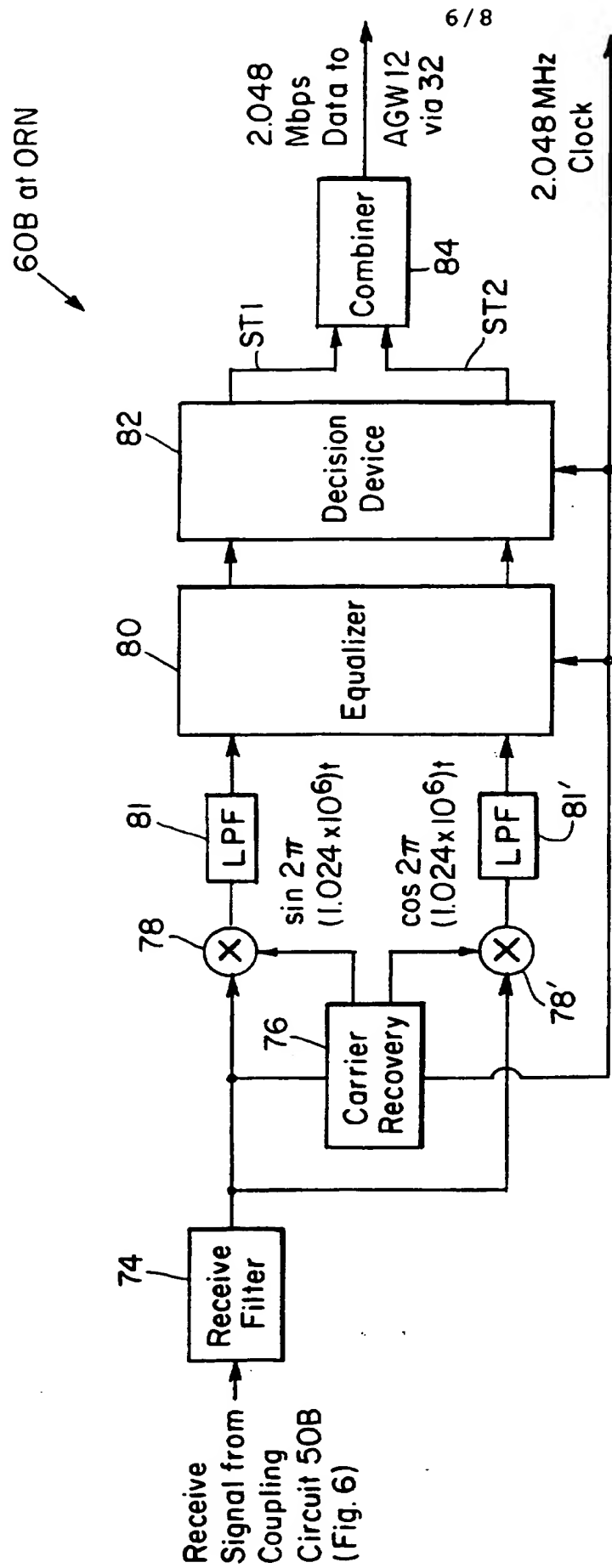


FIG. 8
UPSTREAM RECEIVER/DEMODULATOR at ORN

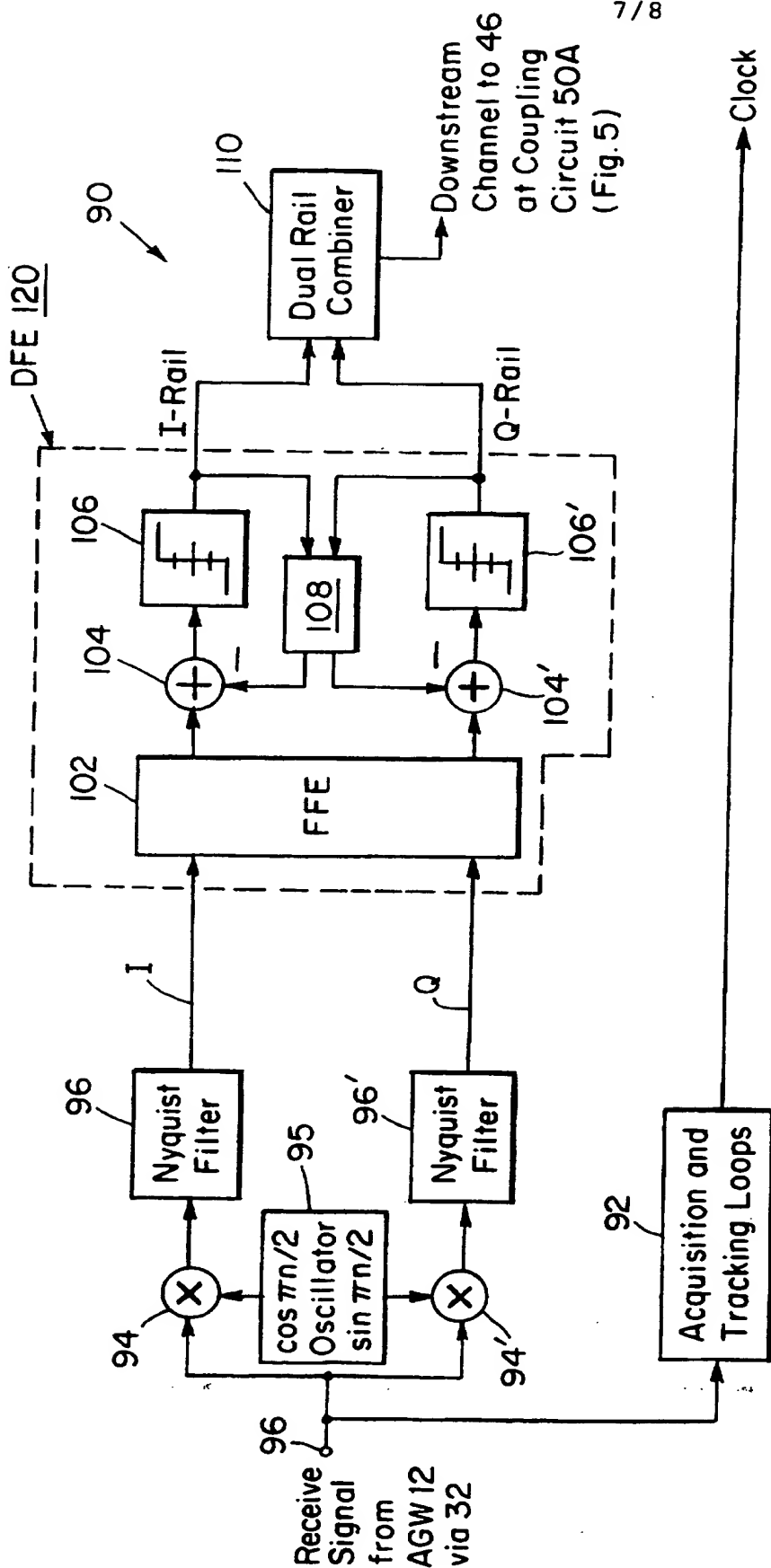


FIG. 9
DOWNSTREAM TRANSMITTER/MODULATOR at ORN 14

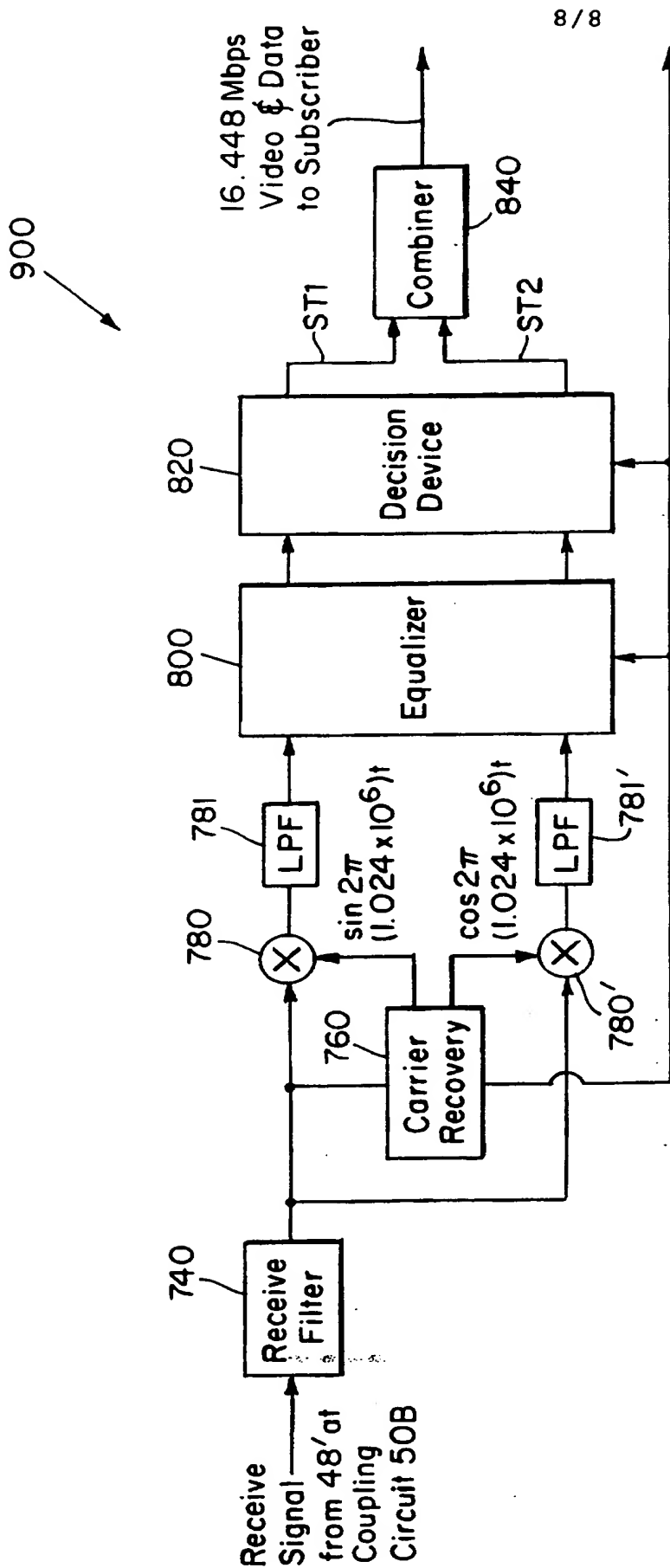


FIG. 10
DOWNSTREAM DEMODULATOR

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/07910A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04M11/06 H04N7/10 H04L12/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04M H04N H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|---|--|
| X | INTERNATIONAL SYMPOSIUM ON SUBSCRIBER LOOPS & SERVICES ISSL 96, 4 - 9 February 1996, MELBOURNE AU, pages 56-61, XP002040951 JOHANSSON A: "VDSL-BROADBAND OVER COPPER" see the whole document --- | 1,2,5-7, 10,11, 15-26 |
| X | ELECTRONIC DESIGN, vol. 43, no. 20, - October 1995 CLEVELAND US, page 51/52, 54, 59/60 XP000550493 GOLDBERG L: "BRAINS AND BANDWIDTH: FIBER SERVICE AT COPPER PRICES" see the whole document --- | 1,5,6, 10,11, 15-17, 19,21, 23,24,26 |
| -/-- | | |

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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- *&* document-member of the same patent family

Date of the actual completion of the international search

17 September 1997

Date of mailing of the international search report

01.10.97

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Authorized officer

Mikkelsen, C

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/07910

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|---|--|
| A | WO 88 06821 A (TELEGENCE CORP) 7 September 1988 see page 10, line 32 - page 12, line 22 --- | 1,3,4,6, 8,9, 11-14, 16,17, 21,24,26 |
| A | COMMUNICATIONS NEWS, vol. 25, no. 6, - June 1988 US, pages 42-43, XP002040952 "TWISTED PAIR AND BALUNS HELP SAVE HALF A MILLION DOLLARS IN WIRING A NEW BUILDING FOR VOICE/DATA" see the whole document --- | 1,3,4,6, 8,9,16 |
| A | INTERNATIONAL SYMPOSIUM ON COMMUNICATIONS ISCOM'95, vol. 2, 27 - 29 December 1995, TAIPEI, pages 693-700, XP002040953 GUPTA D. ET AL.: "PERSPECTIVES ON RESIDENTIAL BROADBAND" see paragraph 2.2 - paragraph 2.3 ----- | 1-26 |

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/07910

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---------------------|----------------------------|---------------------|
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| | | AU 1485688 A | 26-09-88 |
| | | CA 1285668 A | 02-07-91 |
| ----- | | | |